



中国科学院遥感与数字地球研究所
Institute of Remote Sensing and Digital Earth, CAS

Remote sensing of $PM_{2.5}$ near the ground from satellite observation

Ying Zhang

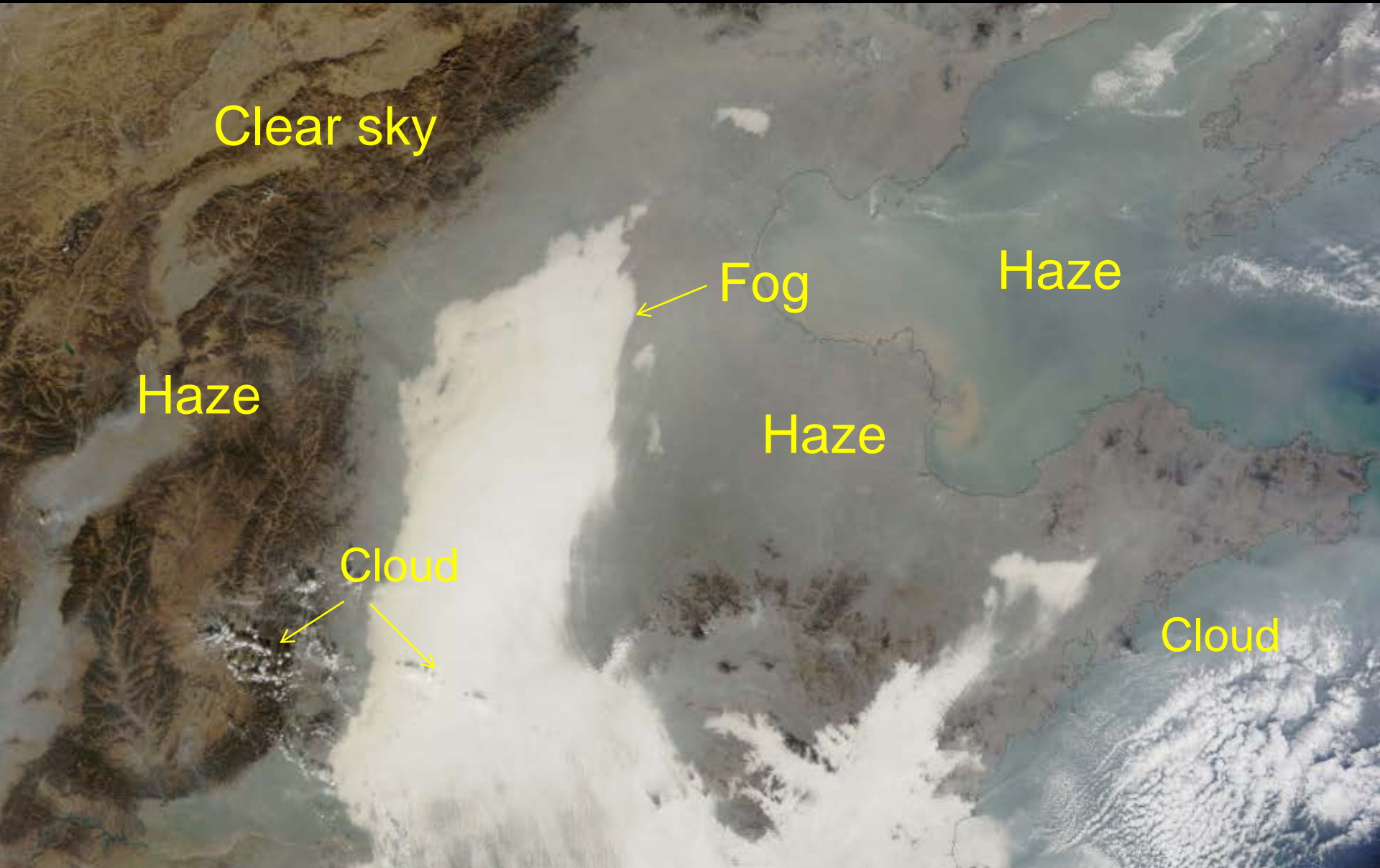
Institute of Remote Sensing and Digital Earth,
Chinese Academy of Sciences



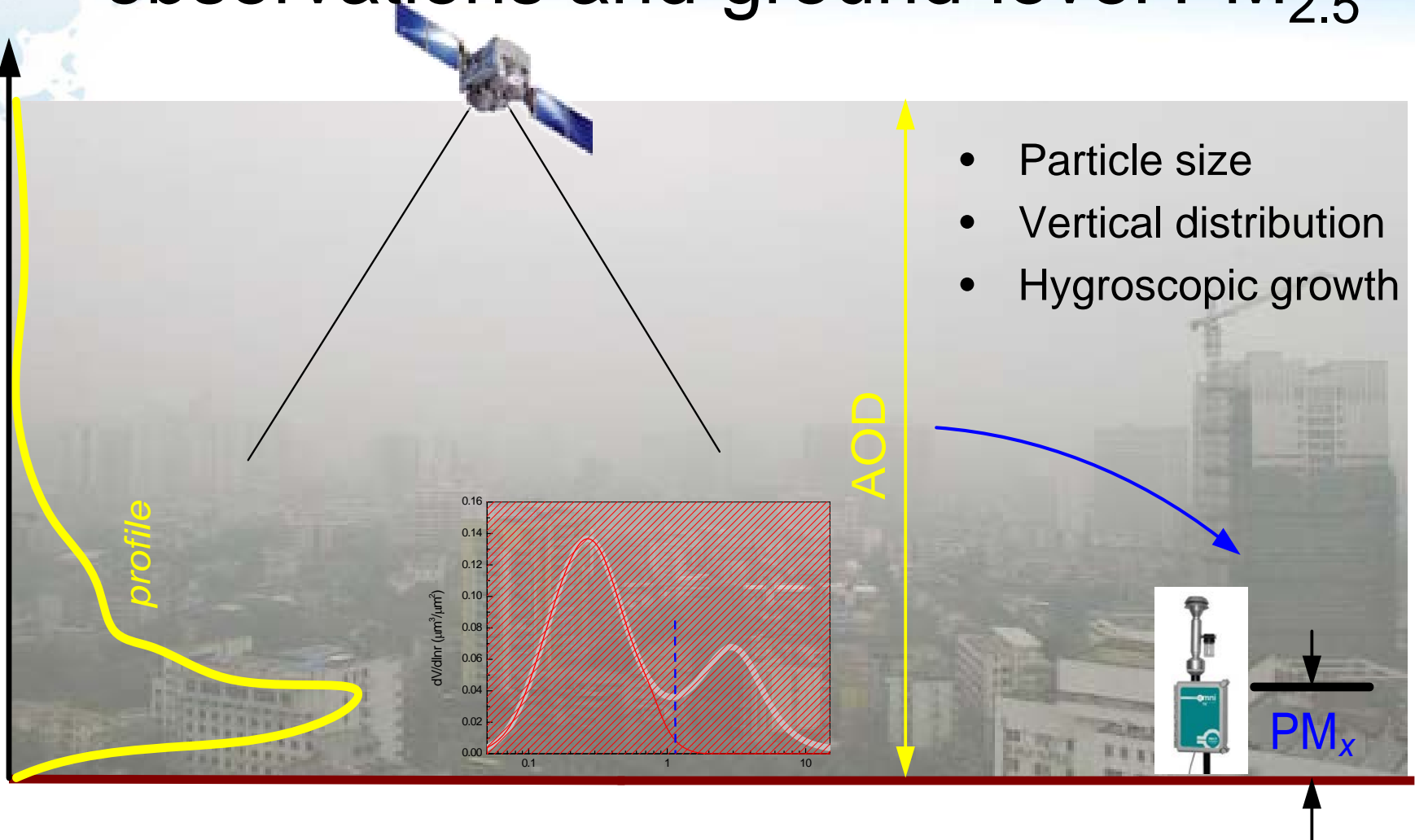
2018/05/22



Observe the haze in MODIS image

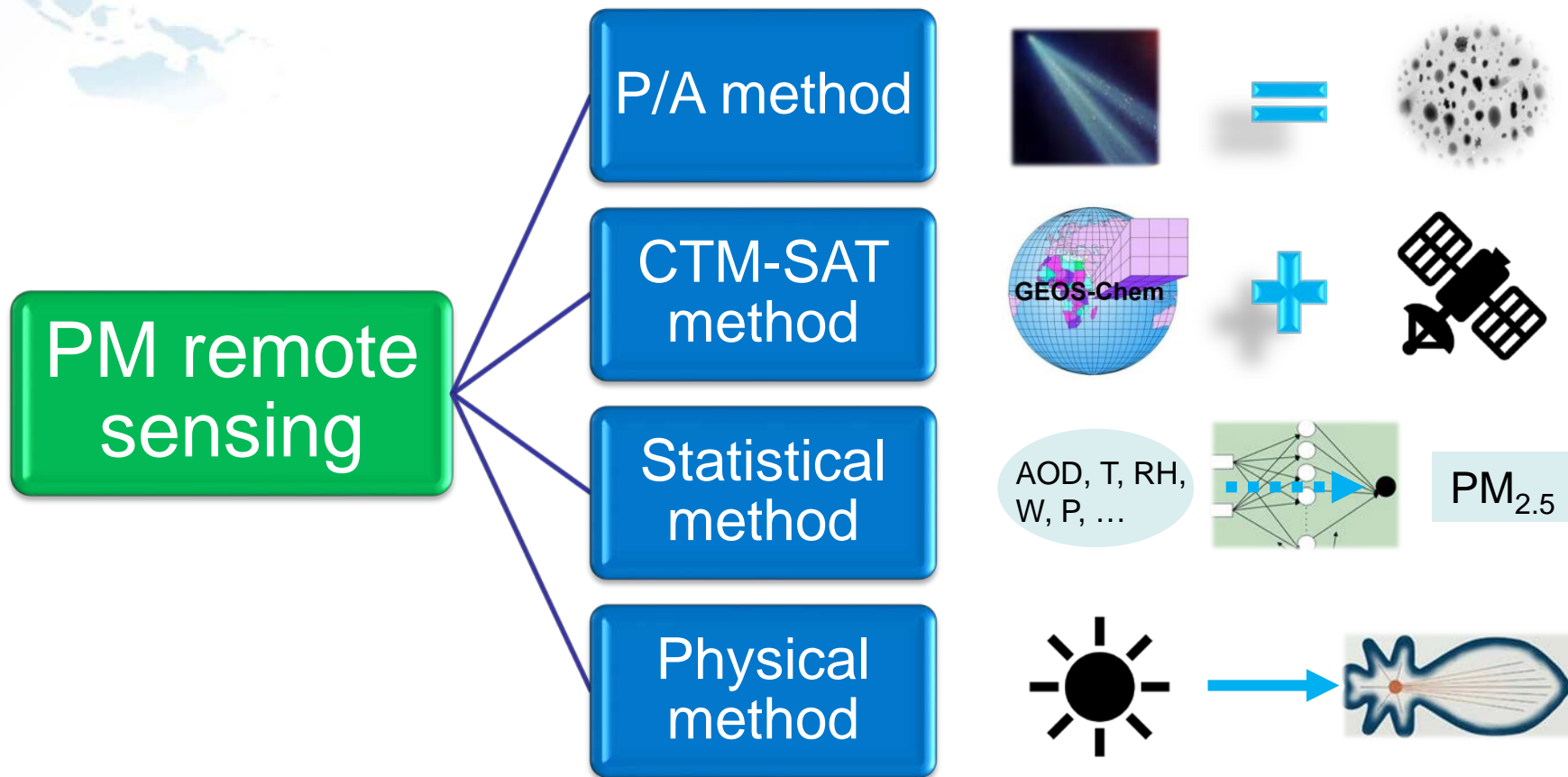


Gap between remote sensing observations and ground-level $PM_{2.5}$



Aerosol optical depth (AOD) is the sum of aerosol extinction in columnar atmosphere.

PM_{2.5} remote sensing method



P/A method

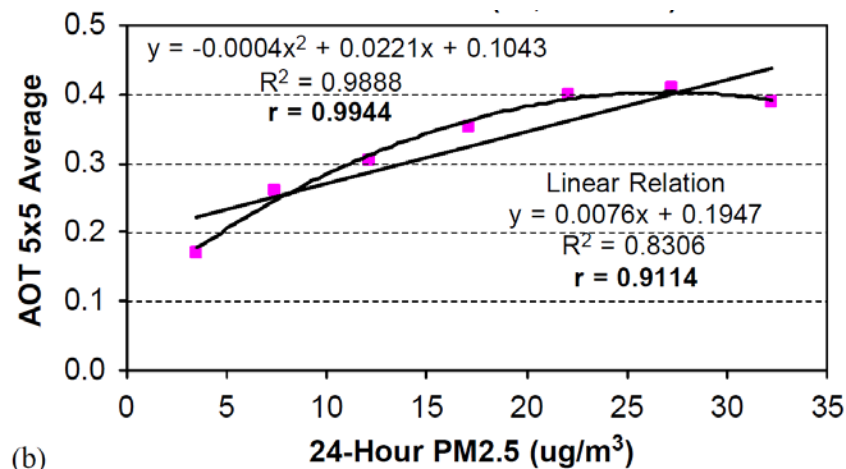
- The relationship between PM_x and AOD is roughly described as a linear dependence.

$$PM = a \cdot AOD + b$$

Chu et al., 2003

Wangle and Christophers, 2003

- But it is a non-linear dependence including complex impacts on particle size, components and shapes.



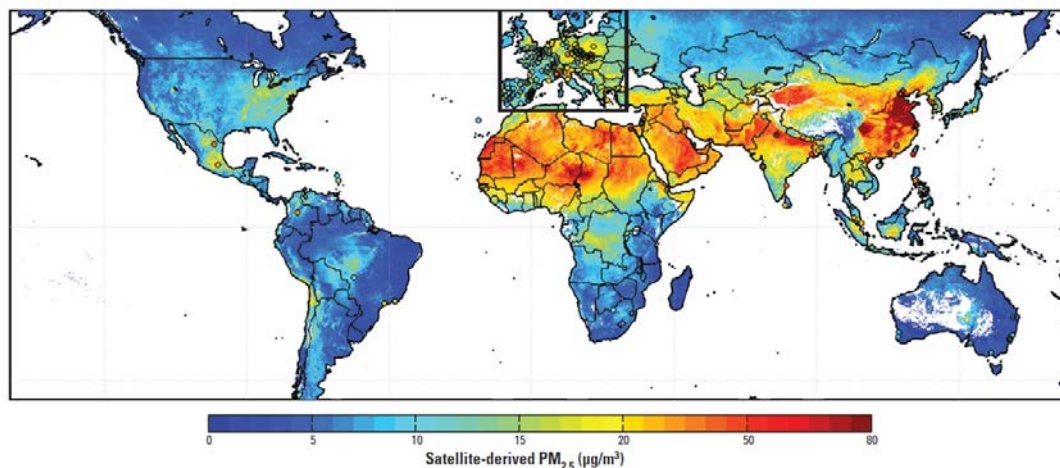
(b)

Hutchison et al., 2005

CTM-SAT method

- To solve the non-linear problem, the satellite observation (SAT) are coupled with chemical transport model (CTM) to estimate the long-term and wide-range PM concentrations.

$$PM = \frac{PM^{sim}}{AOD^{sim}} AOD^{sat} = \eta \cdot AOD^{sat}$$



- Low accuracy in short term
- Relative inferior correlation

Statistical method

- Statistical methods are widely used to estimate PM concentrations based on long-term satellite and ground-based measurements because the **high correlation can be obtained**.



- The **re-calibration** must be executed once the study areas and periods are changed.
- The **physical mechanism** is discarded to a certain degree.

Physical method

- The theoretical formulas of physical method are derived by Koелеmeijer et al. (2006), but **S** is hard to know.

$$PM = AOD \frac{\rho}{Hf(RH)} \cdot \frac{4r_{eff}}{3\langle Q_{ext,dry} \rangle} = AOD \frac{\rho}{Hf(RH)} \mathbf{S}$$



$$PM_{2.5} = AOD \cdot \mathbf{FMF} \frac{\rho}{Hf(RH)} \mathbf{S}$$

Nicolantonio et al., 2007

AOD_f

Parameterization	spectrum	Refs.
$PM_{10} = f(\sigma_e)$	355 nm	Raut et al. (2009a, 2009b)
$r_{eff} = f(\alpha)$	550 nm	Kokhanovsky et al. (2009)
PMRS $S = f(FMF)$	500 nm	Zhang and Li (2015)

Fine mode fraction (FMF) is the fraction of fine-mode aerosol extinction in total AOD.

Define S to be VE_f

- We define a columnar volume-to-extinction ratio of fine particulates (VE_f) to convert AOD_f to columnar fine particle volume $V_{f,column}$:

$$VE_f = \frac{V_{f,column}}{AOD_f}$$

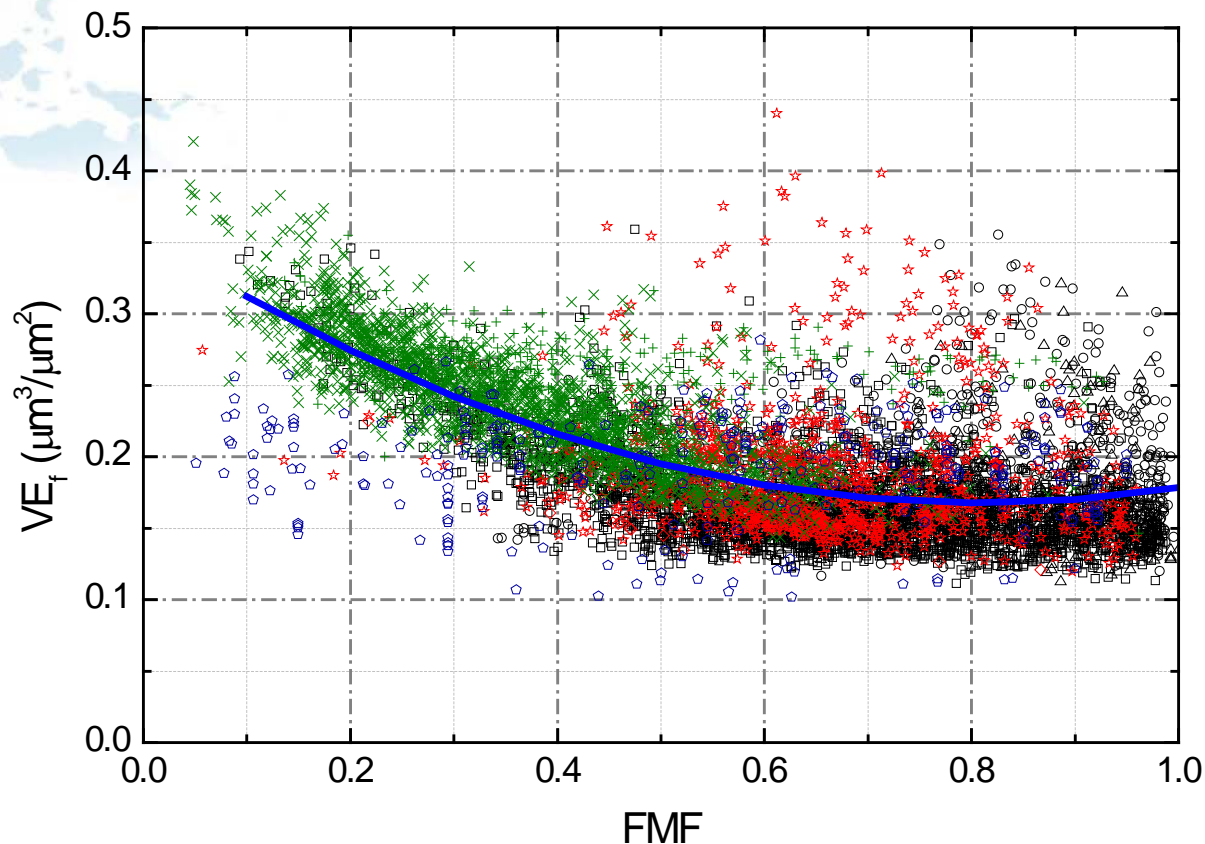
- Then, we can obtain the final formula on $PM_{2.5}$:

$$PM_{2.5} = AOD \frac{FMF \cdot VE_f \cdot \rho_{f,dry}}{PBLH \cdot f_o(RH)}$$

The term VE_f in the numerator is circled in red, with a red arrow pointing to a red letter S above it.

How to obtain the VE_f ?

Parameterization of VE_f



AERONET sites:

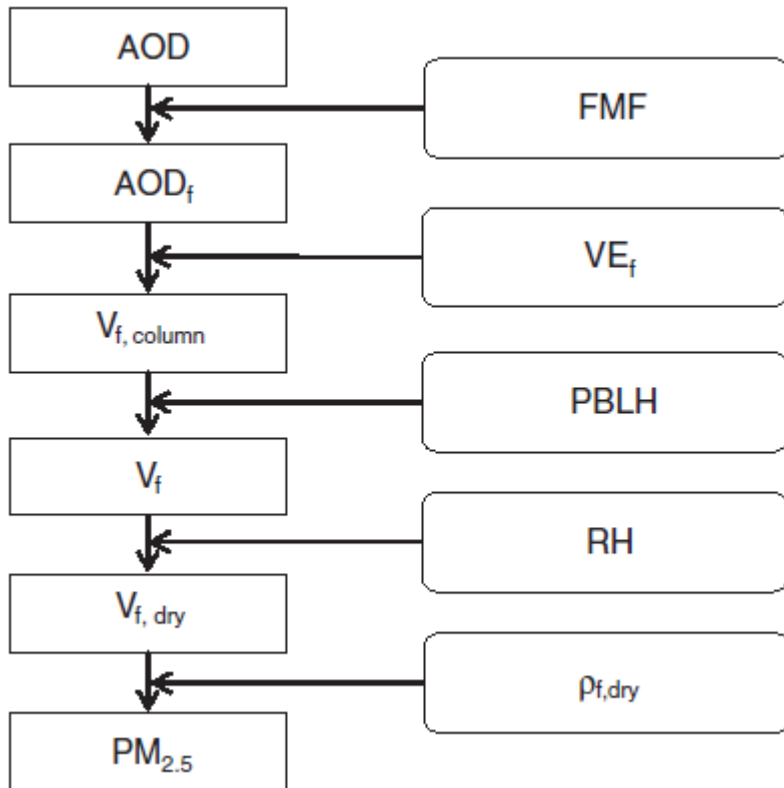
- Beijing (3066)
- GSFC (914)
- △ Mexico City (229)
- ★ Cuiaba (961)
- ◇ Mongu (25)
- × Solar Village (1873)
- + Capo Verde (430)
- Ascension Island (316)

AEROSOL TYPE:

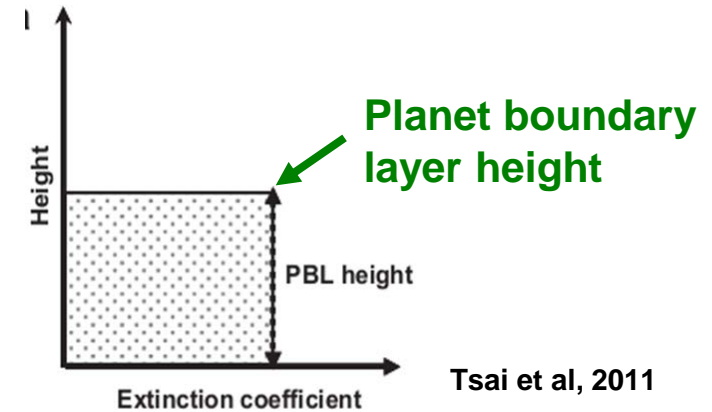
- Urban-Industrial
- Biomass Burning
- Desert Dust
- Oceanic

$$VE_f = 0.2887 FMF^2 - 0.4663 FMF + 0.356 \quad (0.1 \leq FMF \leq 1.0).$$

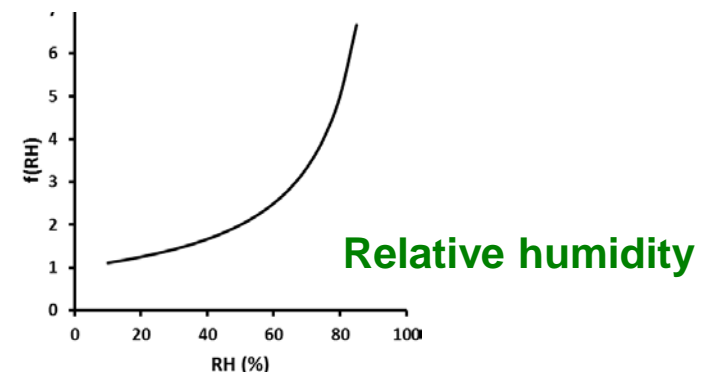
Other assumptions in PMRS method



Uniform mixture model in the PBL

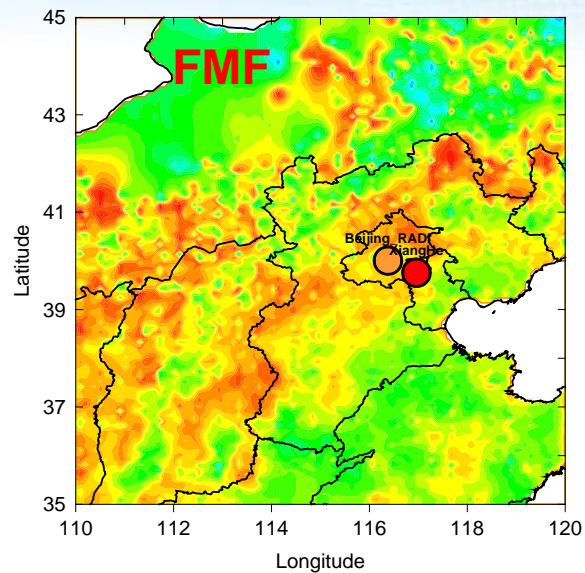
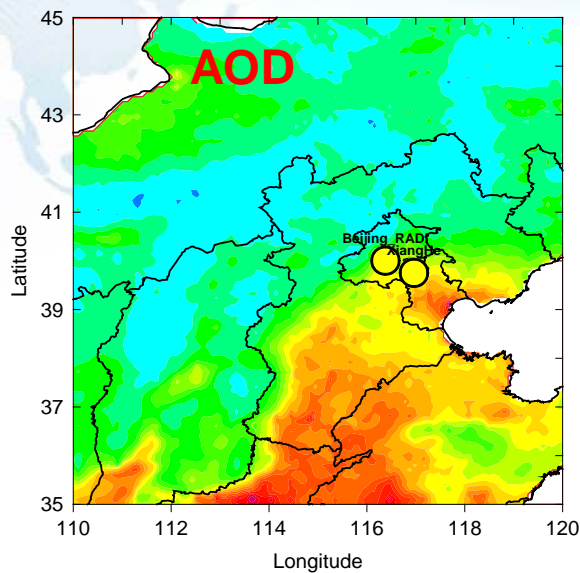


Hygroscopic growth model $f(RH)=a(1-RH/100)^{-b}$

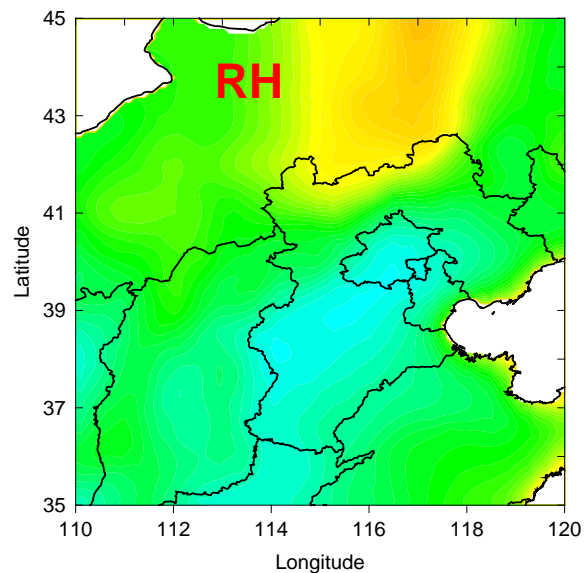
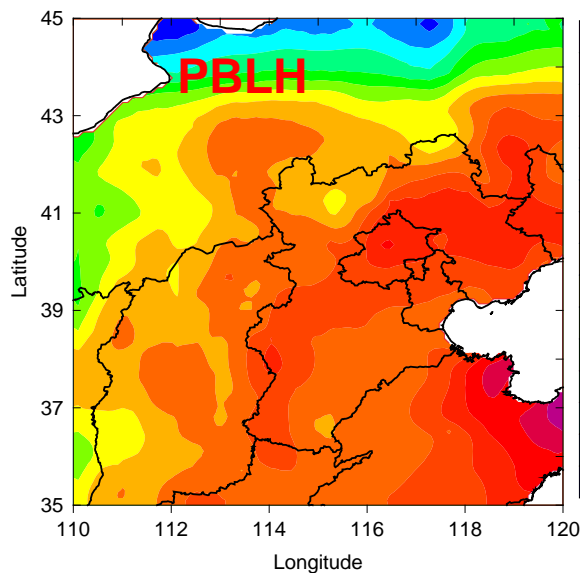




Key parameters

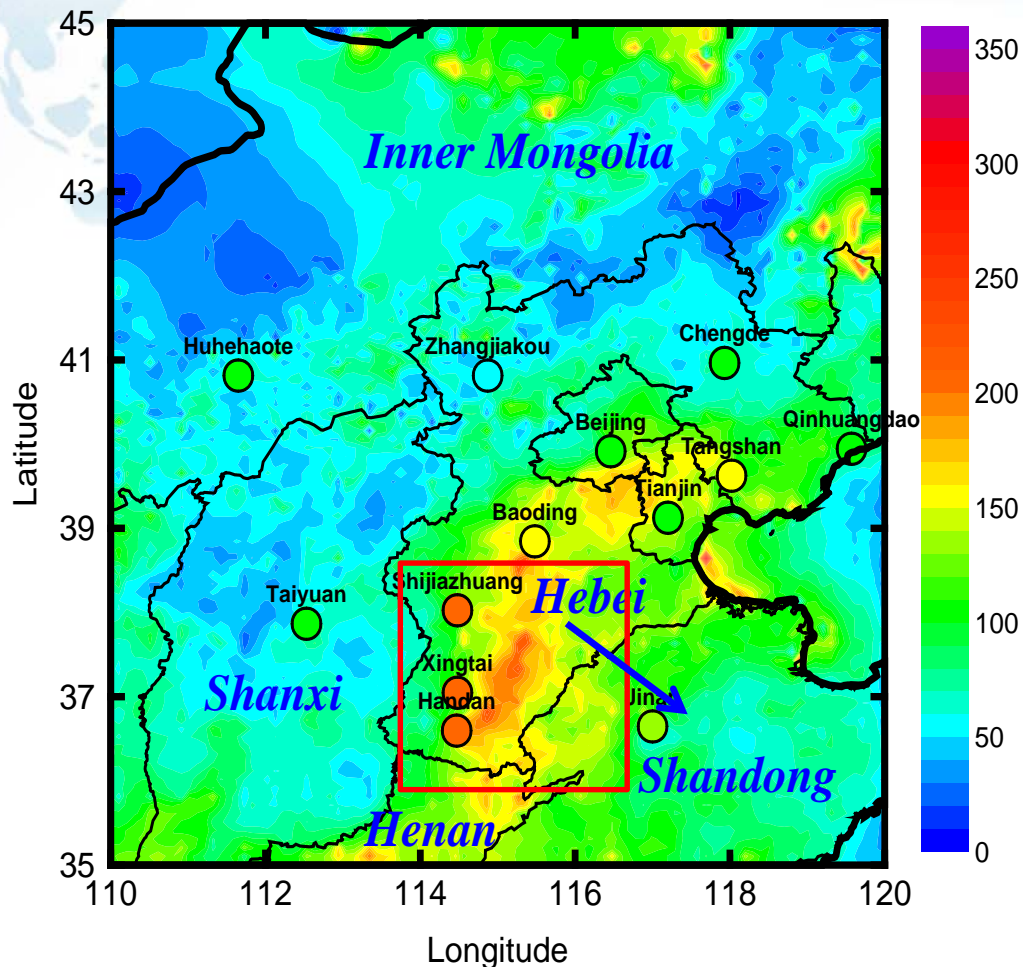


**MODIS
products**



**WRF
simulation**

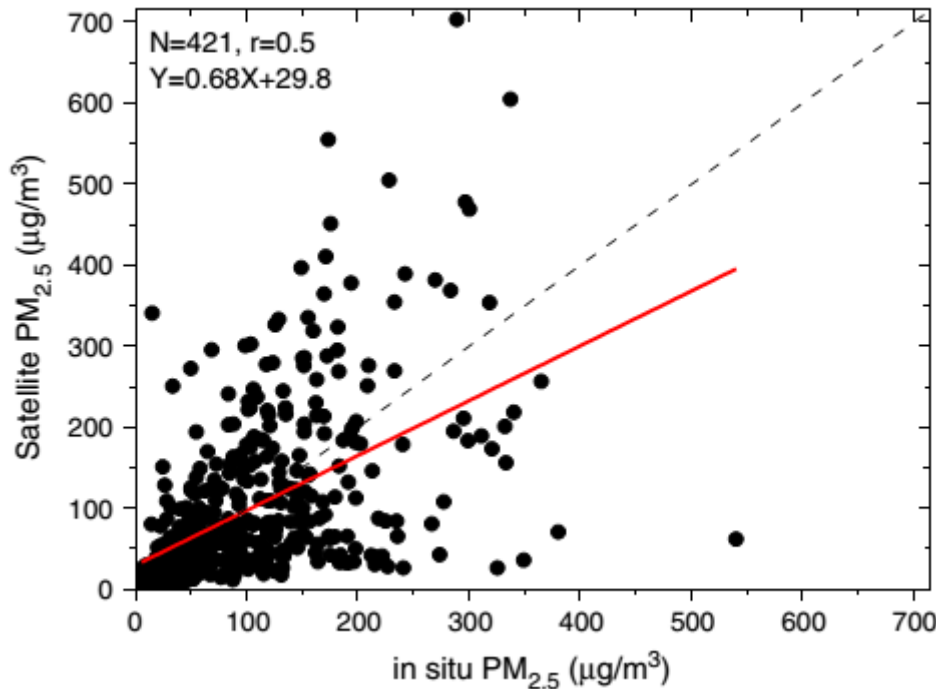
Mean PM_{2.5} near the ground



Mean PM_{2.5} mass concentration near the surface over North China from Oct. 1st to Dec 31st., 2013.

- It shows the high-level PM_{2.5} mass concentration over the south of Hebei province.
- The PM_{2.5} concentration sharply decreases from south of Hebei to north of Shandong.
- The mean PM_{2.5} mass concentration from PMRS model is close to the observations ($101\mu\text{g}/\text{m}^3$ vs $105\mu\text{g}/\text{m}^3$)

Compared with hourly site observation



Error sources:

- 1) Error of the key parameters:
 - AOD, FMF, PBLH, RH...
- 2) Some differences are from temporal-spatial representativeness between satellite and site observations:
 - Instantaneous vs hourly
 - Pixel vs point

$$\frac{\delta PM_{2.5}}{PM_{2.5}} = \sqrt{\left(\frac{\delta AOD}{AOD}\right)^2 + \left(\frac{\delta FMF}{FMF}\right)^2 + \left(\frac{\delta PBLH}{PBLH}\right)^2 + \left(\frac{\delta VE_f}{VE_f}\right)^2 + \left(\frac{\delta f_o(RH)}{f_o(RH)}\right)^2 + \left(\frac{\delta \rho_{f,dry}}{\rho_{f,dry}}\right)^2}$$

↓ 11%
↓ 33%
↓ ?
↓ 14%
↓ 12%
↓ 28%

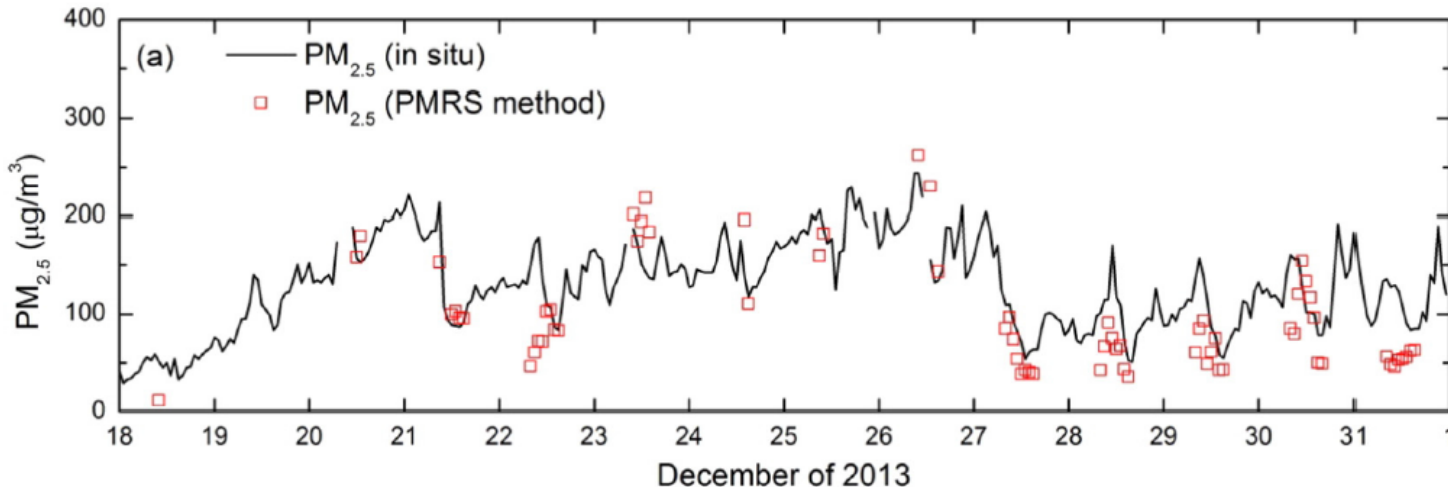
Not evaluated



Validated by ground-based experiment

Instrument	Observation	Period	Data
Sun-sky radiometer	Day time (no rain)	Dec 18-31	AOD, FMF, SSA, dV/dlnr
CRD Spectrometer	24-hr continuous	Dec 24-31	σ_{ext}
Lidar	24-hr continuous	Dec 14-31	PBLH
PM monitor	24-hr continuous	Dec 14-31	PM _{2.5}
Meteorological station	24-hr continuous	Dec 14-31	RH

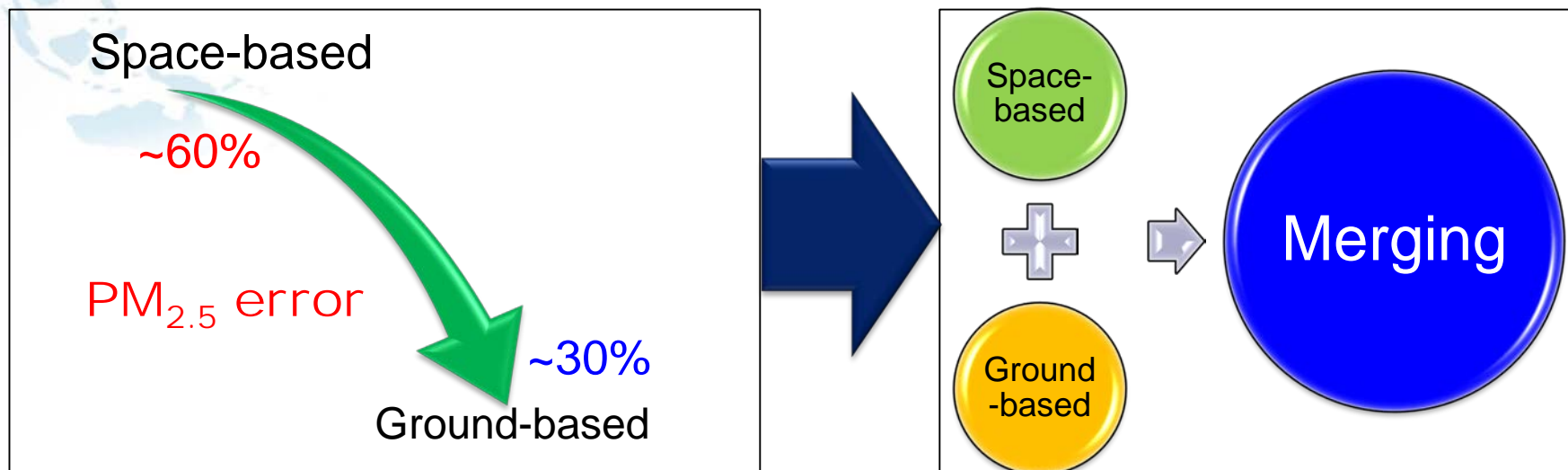
Low error



Li et al., 2016

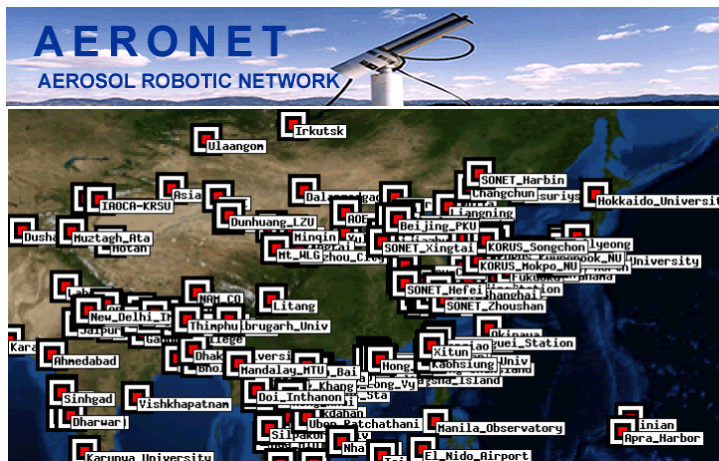
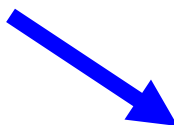
- The average relative uncertainty on the remotely sensed hourly PM_{2.5} is about **31%** by comparing with site observations, and absolute error is **38.8 µg/m³**.

How to decrease the FMF error ?

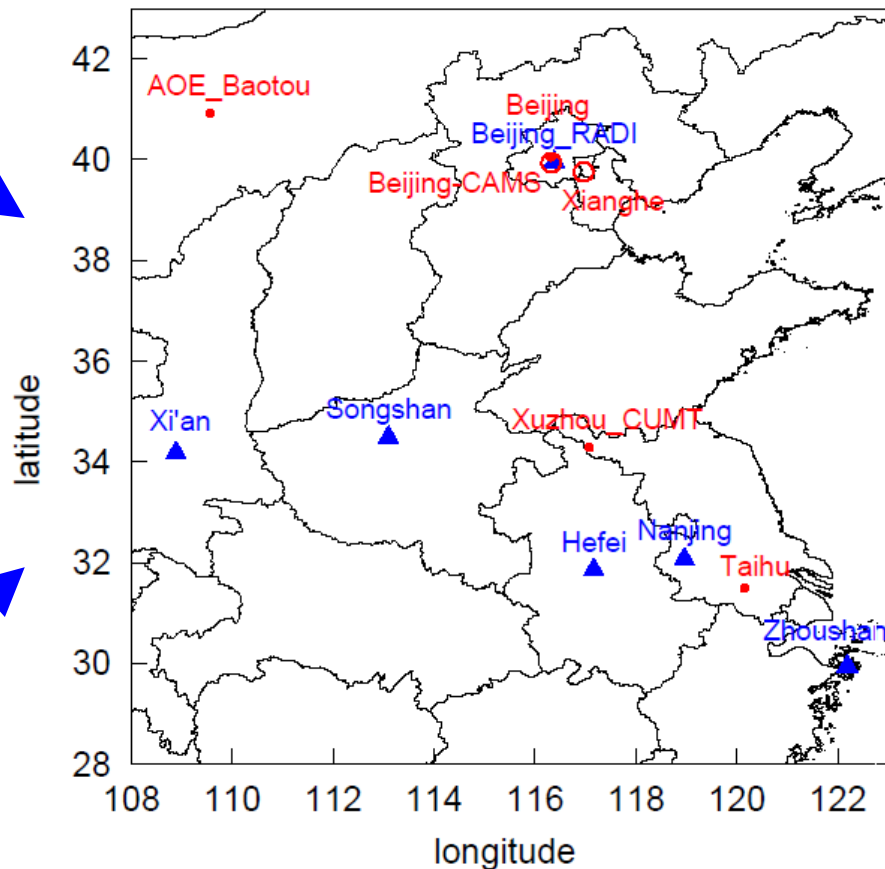


- The error of PM_{2.5} is declined by using ground-based observation from about 60% (Satellite) to 30% (GB obs.).
- Merging FMF between MODIS and Ground-based observation using [universal kriging method](#).

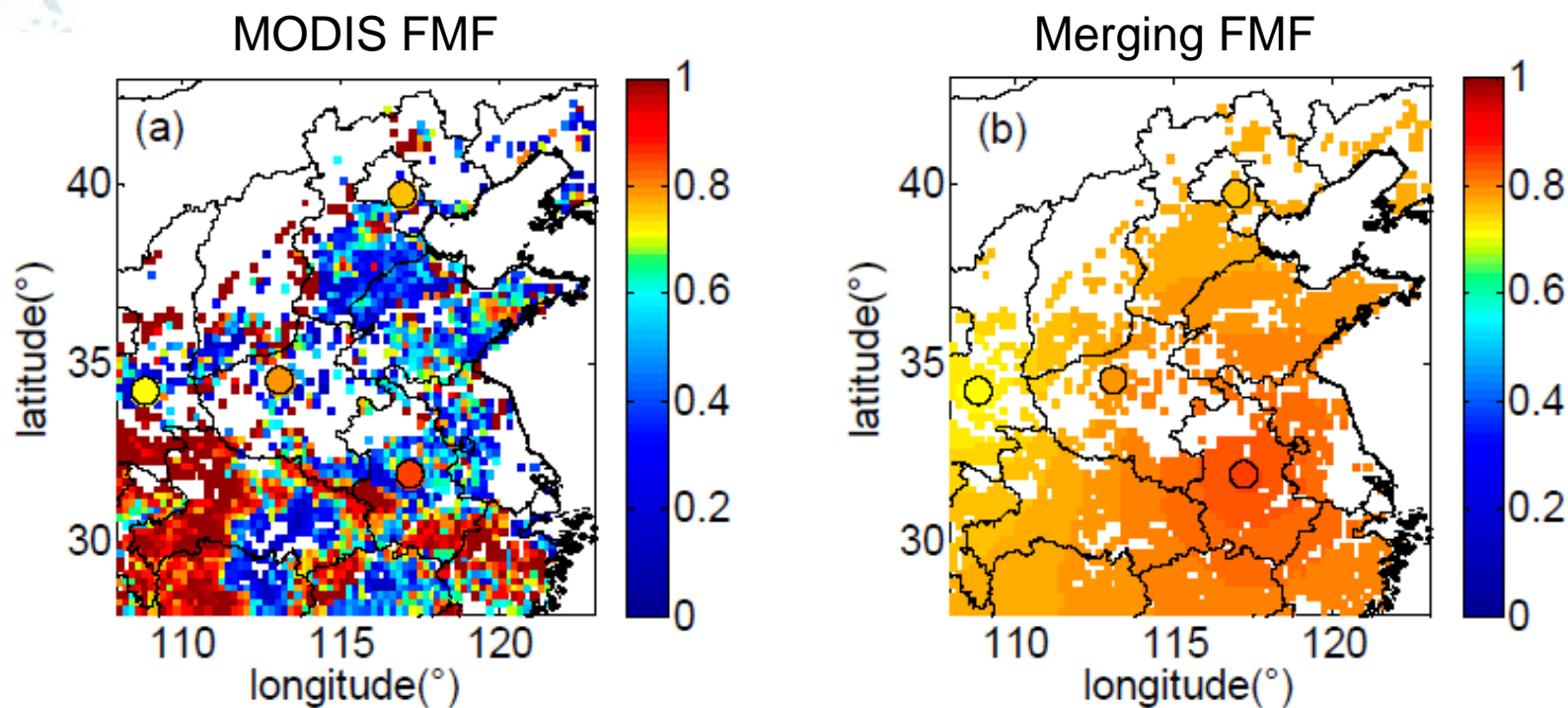
Ground-based FMF



Study area



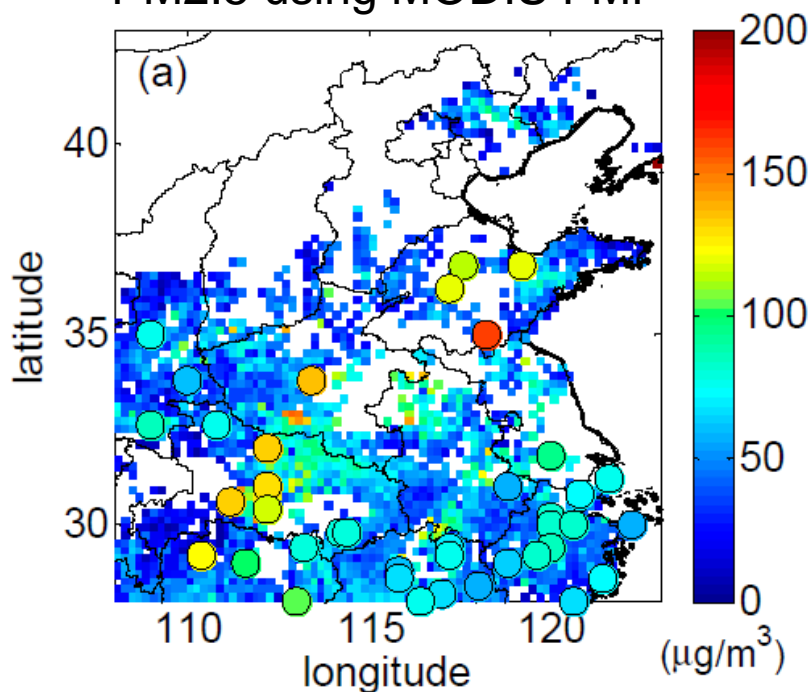
Comparison of FMF



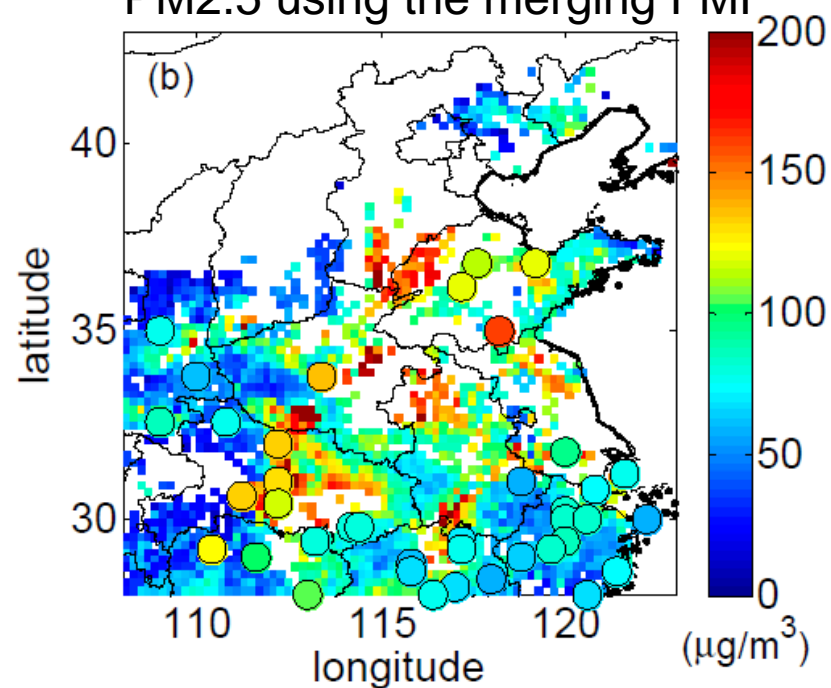
- The merging FMF distribution is more consistent with the AERONET and SONET FMF.
- The FMF error is decreased from 0.38 to 0.13 (MODIS-obs. v.s. Fusion-obs.).

Comparison of PM_{2.5}

PM_{2.5} using MODIS FMF



PM_{2.5} using the merging FMF



- The high-level PM_{2.5} present in the North China and the Sichuan basin, which is more consistent with the in situ PM_{2.5} measurements.



Conclusions

- A new physical method (PMRS) is established to estimate the $PM_{2.5}$ near ground.
- The mean error of estimated $PM_{2.5}$ by ground-based remote sensing is **31%**, but larger uncertainty is involved by FMF products.
- The MODIS FMF errors can be decreased by merging ground-based observations, helpful to improve the accuracy of $PM_{2.5}$.

THANKS FOR YOUR ATTENTION !



www.radi.cas.cn